DEAP & CLEAN Detectors for Low Energy Particle Astrophysics

Andrew Hime

Physics Division, MS H803, Los Alamos National Laboratory
Los Alamos, NM 87545, USA

Abstract. Liquid cryogens such as neon and argon hold promise as targets for low-energy solar neutrinos and WIMP dark matter in conceptually simple detectors exploiting the unique properties of scintillation light in these liquids.

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INTRODUCTION

The field of solar neutrino physics has emerged in recent years to one of precision measurements aimed at two broad questions:

1. Is our model of neutrino mass and mixing complete or are other, subdominant, mechanisms at play?
2. Is nuclear fusion the only source of the Sun's energy?

Within this context, the multidivisional study of the APS, *The Neutrino Matrix,* made as one of its top three recommendations the development of a real time detector to measure the dominant, low-energy (pp-fusion) solar neutrino spectrum with a goal post of 1% accuracy in mind to tackle these questions [1]. With the discovery of non-zero neutrino mass in solar, reactor, and atmospheric neutrino experiments, we now know that neutrinos constitute at least as much mass as do all of the stars in the Universe but that they cannot provide the energy density or large scale structure required of non-baryonic cold dark matter, the evidence for which is now well established [2,3]. One of the leading candidates for this cosmological dark matter requires new physics in the form of Weakly Interacting Massive Particles (WIMPs), the likes of which could be directly detected as they recoil in targets of ultra-low background, low-energy threshold detectors [3].

CLEAN

The detection of pp-solar neutrinos and WIMP dark matter both require massive detectors with low-energy threshold and unprecedented constraints on radioactive background. It would be ideal to realize a technology capable of the simultaneous detection and discrimination of both low-energy solar neutrinos and dark matter. Dubbed CLEAN (Cryogenic Low Energy Astrophysics with Neon), an ultra-pure and massive target of liquid neon (LNe) could be exploited in a conceptually simple detector for this purpose [4,5]. Several unique properties of scintillation light in LNe, in concert, make this possible:

1. LNe contains no long-lived radioisotopes and can be purified to unprecedented levels using conventional cold-traps.
2. LNe is transparent to its own scintillation light and dense enough to serve as a self-shielding medium.
3. Position reconstruction in a LNe detector can be achieved using PMT charge and timing distributions allowing, in conjunction with 1 & 2 above, fiducialization of an ultra-pure target volume.
4. LNe scintillates strongly in the extreme ultraviolet (EUV) allowing for the detection of events with very low energy threshold.
5. Commercially available photomultiplier tubes (PMTs) are available with adequate purity levels to make a large scale, LNe detector feasible.
6. Pulse shape discrimination is possible using two distinct states of scintillation light, making possible a truly dual-purpose detector of low-energy solar neutrinos and WIMP dark matter.

The CLEAN detector envisioned would exploit ~ 100 tonnes of LNe contained in a spherical detector volume with radius ~ 300 cm and surrounded by several thousand PMTs submerged in the liquid. Event position would be reconstructed from the charge and timing distribution of scintillation light collected in the PMT array, providing an ultra-pure fiducial volume free from PMT background and serving as a target of pp-solar neutrinos and WIMP dark matter. In this scenario, solar neutrinos would act as a background to low-energy WIMP recoils, however, the two classes of events (electron-like from elastic scattering of solar neutrinos *versus* recoil events from WIMP-nucleus scattering) can be discriminated from one another owing to the different ratio of prompt-to-late light in the scintillation time distribution. Detailed simulations, assuming nominal properties of scintillation light in LNe, indicate that such a detector could achieve the desired precision of ~1% in the pp-solar neutrino flux whilst simultaneously probing for WIMP dark matter with unprecedented sensitivity [5].

The CLEAN detector envisioned is technically challenging, about half the scale of the SNO detector and operating at 27 K. Furthermore, the viability of the detector concept is sensitive to the details of scintillation light properties in LNe and these properties require better quantification before being able to design the full scale CLEAN detector [5]. An intermediate step is presently underway to design and construct a detector of ~100 kg (mini-CLEAN) to demonstrate all salient features relevant to the engineering design of a much larger LNe detector. Based upon recent studies (see below) of the properties of scintillation light in liquid argon (LAr), such a detector could serve as a highly competitive search for WIMP dark matter by simply exchanging the LNe with LAr.

DEAP

The search for WIMP dark matter at ever increasing levels of sensitivity requires detectors scalable in target mass to ~1000 kg and beyond whilst maintaining the ability to reject ubiquitous backgrounds that would otherwise fog a signal for dark matter. In recent years, efforts have turned to the potential use of noble liquids to search for WIMPs due to the possibility of scaling to large target masses while achieving the very low energy thresholds and radiopurity requirements required of a sensitive WIMP search. Reducing the background levels requires careful selection of detector construction materials low in natural radioactivity and relies on novel techniques to discriminate ionizing radiation from the nuclear-recoil signature of a scattering WIMP. Developments underway using liquid xenon [6,7] and LAr [8] aim to achieve this discrimination by measuring both scintillation light and the ionization yield through drifting of electrons in the liquid. Recent work at Los Alamos National Laboratory [9,10] has a identified a conceptually simple approach to background discrimination in LAr by exploiting the distinct ratio of triplet to singlet scintillation light in LAr that arises from ionizing events relative to nuclear recoil events. Dubbed DEAP for Dark matter Experiment with Argon and Pulse shape discrimination, a detector is under design and construction with the aim to stage a ~10 kg LAr experiment deep underground. This DEAP-I detector will be used in order to demonstrate the low-background and low-energy threshold potential of the DEAP concept and will hopefully serve in the search for WIMP dark matter. This activity will proceed in parallel with efforts to realize a ~100 kg mini-CLEAN detector capable to be operated with both LNe and LAr.

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